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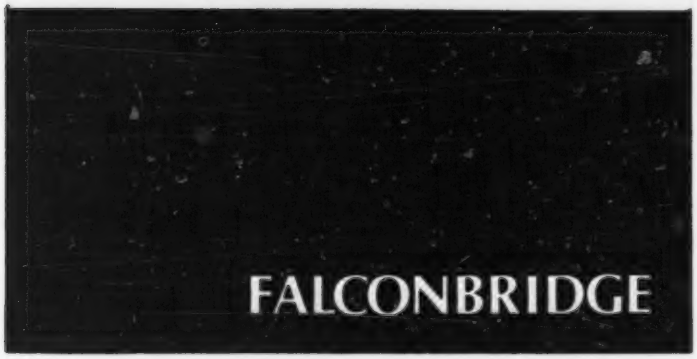
FALCONBRIDGE METALLURGICAL LABORATORIES

DETERMINATION OF ABRASION RESISTANCE OF EXPERIMENTAL PLATE STEELS



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FALCONBRIDGE NICKEL MINES LIMITED
METALLURGICAL LABORATORIES
THORNHILL, ONTARIO

FALCONBRIDGE METALLURGICAL LABORATORIES

DETERMINATION OF ABRASION RESISTANCE OF EXPERIMENTAL PLATE STEELS

by
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ABSTRACT

Seven experimental steels, produced by microalloying and direct quenching, and three commercial, wear resistant plate steels were tested for abrasion resistance. The experimental steels had similar low stress and high stress abrasion resistance to conventional low alloy steels with similar hardness levels. The abrasion resistance of steels appears to be a complex function of composition, thermo-mechanical treatment, subsequent heat treatment and the microstructure produced by these variables. Microalloying would probably be attractive for producing weldable abrasion resistant plate, if hardness levels equivalent to quenched and tempered steels can be produced at lower carbon concentrations. This was not achieved with the alloys tested. A systematic study should be undertaken to isolate the effects of each of the different variables on abrasion resistance.

BACKGROUND

Work at CANMET, Physical Metallurgy Research Laboratories (PMRL) showed that, by direct quenching microalloyed plate steels, hardnesses equivalent to conventional quenched and tempered steels could be obtained at lower carbon concentrations and lower total carbon equivalent values.[1,2] The direct-quenched steel was expected to exhibit superior toughness and weldability with adequate abrasion resistance, for use in applications such as truck boxes, ore hoppers, gravel crushers and scraper blades. PMRL prepared seven, experimental steels based on the micro-alloying, direct-quenching concept. Falconbridge Metallurgical Laboratories (FML) were contracted to perform abrasion resistance evaluations of these materials (DSS File No. 25SR 23440-0-9182. Contract Ser. No. OSR81-00026).

STATEMENT OF WORK

FML designed the procedures and modified equipment for determining the abrasion resistance of different plate steels for two types of applications, i.e. low stress, scratching abrasion applications and high stress, grinding abrasion applications. Measurements of abrasion resistance were made on samples of seven, experimental steels supplied by PMRL and three, commercial steels obtained by FML. The results of these measurements were considered in terms of the compositions and microstructures of the various steels.

Work was conducted in general accordance with the FML technical proposal[3] and the detailed outline of optional proposal #1 [4].

ALLOYS STUDIED

PMRL submitted seven, experimental steels for abrasion testing. Four of these compositions (Mn/Nb: 1-4) were microalloyed steels containing 0.06%Nb, with carbon contents ranging from 0.10% - 0.19%. The other three, experimental steels (EXP 360: 1-3) were modifications of the commercial, CHT 360 composition. Three, commercial plate steels were also tested as reference materials. These alloys were CHT 100, a constructional plate steel, and CHT 360 and 475, both wear resistant grades. Compositions for all alloys tested are listed in Table I.

The experimental steels were induction melted under an argon cover. The charge material was electrolytic iron for the Mn/Nb steels (resulting in low sulphur contents) and Stelco billet for the EXP 360 steels. High purity ferro-alloys were used for the alloy additions and all steels were aluminum-killed.

The Mn/Nb steels were poured into 45 kg ingots which were cropped and sliced longitudinally for direct rolling into plate. The EXP 360 steels were cast into rectangular, tapered, 45 kg billets. These were cropped, chamfered to facilitate direct rolling, soaked at 2000°C and rolled to 57 mm thick slabs. The slabs were cut into two pieces for rolling to plate. All experimental steels were then control-rolled to 13 mm thick plate using the rolling schedules listed in Table II. [5]

The commercial, plate steels were supplied as finished 1/2 inch (~13 mm) plate. During manufacture, these products are hot-worked, re-austenitized, quenched and tempered at various temperatures given below.

HEAT TREATMENT AND SAMPLE PREPARATION

All experimental steels, with the exception of EXP 360-3, were water-spray quenched immediately after the final rolling pass. The spray quench resulted in a mean cooling rate between 750°C and 500°C of 85°C/second at the mid-thickness of the plates. EXP 360-3 was air-cooled after the final rolling pass due to a malfunction in the quenching equipment. This alloy was subsequently re-austenitized, quenched and tempered at 370°C for 1 hour. Steels Mn/Nb-1 and EXP 360-2 were supplied in the direct quenched condition. The other plates were tempered for 1 hour at temperatures of 300°C (EXP 360-1), 315°C (Mn/Nb-2 and Mn/Nb-3) and 370°C (Mn/Nb-4 and EXP 360-3).

After hot-working, the commercial steels were homogenized at 900-950°C and water quenched. Tempering was then performed at temperatures of 650°C (CHT 100), 370°C (CHT 360) and 290°C (CHT 475). All processing of the commercial steels was completed by the manufacturers.

Identification numbers, heat-treated hardnesses and graph symbols for all test materials are listed in Table III.

After processing, abrasion test samples were rough-cut from the steel plate. These samples were then ground to the configuration and approximate dimensions shown in Figure 1. Sufficient metal was ground from each test face to ensure the removal of any decarburized material.

TEST METHODS

Low stress, scratching abrasion tests were performed according to American Society for Testing and Materials (ASTM) standard practice G65-80, procedure B. The test equipment (Figures 2-3) was modified from existing equipment to comply to the standard. The modifications were described in optional proposal #1 and the interim progress report.[6] In the low stress test, light pivotal loading forces a flat specimen against a rotating rubber wheel that drags gravity fed abrasive across the sample surface. This dry sand, rubber wheel abrasion test is thought to simulate wear as found in sand chutes, spiral classifiers and ore conveyors, where abrasives slide along a metal surface.

High stress, grinding abrasion resistance was measured with a test originally developed at the British Cast Iron Research Association.[7] In this test, (Figures 4-5), a linear bearing applies a 30.6 kg load to a flat sample, which is dragged along a sand covered, steel track. The sample travels at a speed of 0.50 m/sec. This amounts to a distance of 900 m travelled in each 10-minute test interval. Because of the heavy loading, extensive comminution of the abrasive takes place during testing. Therefore, the 5 kg abrasive charge is replaced after every 3 test intervals. The crushing action of the high stress, abrasion test is meant to simulate conditions found in ore grinding equipment.

Both tests use dry, AFS 50/70, subangular silica as an abrasive. Figure 6 shows the wear scars resulting from the two tests. The low stress test produces a polished surface while the high stress abrasion scar is much rougher. The variations in wear scar appearance and texture are a result of different mechanisms of metal removal in the two tests.

Four samples of each steel were tested for two intervals each in the low stress test and three intervals each in the high stress test. Weight losses were measured on a microbalance after each test interval. Every fourth sample tested was a mild steel reference sample, which allowed abrasion factors to be calculated, where:

$$\text{Abrasion Factor} = \frac{\text{Average Weight Loss of Mild Steel Reference Samples}}{\text{Weight Loss of Test Sample}}$$

In alloy rankings, a higher abrasion factor is indicative of better abrasion resistance. The eight, low stress abrasion factors and twelve, high stress abrasion factors calculated for each alloy closed the 95% confidence intervals to within ±9%. Volk [8] describes the calculations used to determine these intervals on the basis of student "t" statistics.

DISCUSSION - COMPARISON OF PLATE STEEL TO COMMERCIAL ALLOYS

A ranking of the test alloys by low stress abrasion resistance is listed in Table IV. As is evident from this ranking, CHT 475 exhibited markedly better abrasion resistance than all of the other steels. Second in the ranking was Mn/Nb-4, showing an abrasion factor approximately 30% less than that of CHT 475. Five other alloys followed, grouped closely between 1.30 and 1.51. Mn/Nb-1, CHT 100 and EXP 360-2 exhibited the poorest low stress abrasion resistance, performing only marginally (<15%) better than mild steel.

Table V lists a ranking of the alloys by high stress abrasion resistance. This ranking shows a narrow range in performance, with CHT 360 exhibiting marginally better abrasion resistance than the other plate steels. Seven steels showed high stress abrasion factors within 13% of CHT 360. Again, EXP 360-2 and CHT 100 exhibited the poorest high stress abrasion resistance, performing less than 15% better than mild steel.

Statistical calculations on abrasion factor means showed that a relatively high level of confidence could be placed in the results from both tests. Ninety-five percent confidence intervals closed to within ±9% are as narrow as can be expected for tests of the type conducted in this evaluation. Table VI lists the probabilities that the calculated, abrasion factor means are not significantly different, on the basis of student "t" statistics. [8] This table shows that the tests measured a statistically significant difference in abrasion resistance between most of the materials, under both low and high stress conditions. However, as explained below, most of these measured differences are of little practical value.

To put into perspective the ranges in abrasion resistance of available materials, Table VII lists abrasion factors for a number of commercial ferrous alloys. Experimental steel Mn/Nb-4 is listed in this ranking for comparative purposes. The ranking shows that white iron hardfacing alloys have low stress abrasion resistance from 4 to 10 times better than the best low alloy steels. The range in high stress abrasion resistance is much narrower, with the best alloys exhibiting abrasion factors between 2.0 and 3.0, as compared to 1.4 for the best low alloy steel. The variation in the ranges of performance between the two tests can be attributed to differences in the metal removal mechanisms.

Having examined the ranges in performance for ferrous alloys, it is evident that improvements in low alloy steels have only a limited practical value. When compared to other ferrous alloys, low alloy steels as a group exhibit only fair abrasion resistance under both low and high stress conditions. FML have previously conducted a study on the effects of composition, heat treatment and hardness on the abrasion resistance of cast, low alloy steels (AISI 43XX and 86XX series). The results of some of these tests are included in Table VII. In the tests, the steels showed only minor variations in abrasion performance, even though hardness ranged from Rc 26 to Rc 60. Low stress abrasion factors were found to vary from 1.1 to 2.7, while high stress abrasion factors for the same steels ranged from 1.0 to 1.4. Tests on numerous low alloy steel weld deposits also showed abrasion factors within these ranges.

None of the experimental steels exceeded abrasion factors determined for the cast materials. However, for low stress abrasion applications, Mn/Nb-4 can be favourably compared to the better low alloy steels.

DISCUSSION - EFFECT OF HARDNESS ON ABRASION RESISTANCE

The effect of hardness on the low stress abrasion resistance of the test alloys is shown in Figure 7. Superimposed on this plot are the results from abrasion tests on low alloy steel castings, performed previously at FML. The experimental steels show slowly increasing low stress abrasion resistance as hardness increases, following the same trend as the low alloy steel castings.

Figure 8 shows the effect of hardness on the high stress abrasion resistance of the test alloys. Again, results from the experimental steels are similar to previously determined results for cast, low alloy steels. However, in this case, hardness appears to have little effect on high stress abrasion resistance.

Both of these trends imply that low alloy steels of similar hardness generally exhibit similar abrasion resistance. This concept applies over a wide range of hardness and under both low and high stress abrasion conditions. Previous studies at FML have indicated that for ferrous alloys in general, marked increases in abrasion resistance do not occur until alloy hardness approaches the hardness of the abrasive (~Rc 68).

DISCUSSION - EFFECT OF COMPOSITION ON ABRASION RESISTANCE

Previous work at PMRL showed that, by direct quenching microalloyed plate steels, hardness equivalent to conventional quenched and tempered steels could be obtained at lower carbon concentrations [1,2]. Hardnesses for the experimental alloys submitted for evaluation ranged from Rc 22-44. As shown in Figure 9, the relationship between hardness and carbon content was approximately linear, with the scatter in the plot probably arising from differences in the heat treatment of the steels after rolling. Superimposed on this plot is a trend from published data [9] showing hardnesses attainable at various carbon concentrations in commercially quenched, carbon steels. All but one of the measured hardnesses for the experimental steels were below the published values. Hardnesses for the commercial steels that did not undergo heavy tempering (CHT 360 and 475) appear to agree with the published values. These trends indicate that the experimental steels submitted for evaluation do not show hardnesses equivalent to conventional quenched and tempered steels at even the same carbon concentrations.

The effects of carbon content on the low and high stress abrasion resistance of the experimental alloys are shown in Figures 10 and 11 respectively. Both trends show that the results from the experimental alloys fall within previously determined trends on cast, low alloy steels. Again, the scatter in these plots appears to be largely an effect of differences in tempering temperature. Under low stress conditions, abrasion resistance is seen to increase slightly with increasing carbon content. Under high stress conditions, carbon content appears to have very little effect on abrasion resistance. The forms of these relationships closely parallel those found in the hardness trends. This is expected, since the hardness and carbon content of the experimental steels are directly related, as shown above.

One aim of the microalloying, direct quenching program was to develop a steel exhibiting superior toughness and weldability with adequate abrasion resistance. For low stress abrasion applications, Mn/Nb-4 may satisfy these requirements. The carbon content of Mn/Nb-4 is approximately 0.1% less than that of CHT 475, the only plate steel with a higher low stress abrasion factor. The lower carbon content may be beneficial in terms of weldability. Mn/Nb-4 also has a lower total alloy content than popular, low alloy steels such as those available in the AISI 43XX and 86XX series. The lower alloy content should improve weldability by reducing hardenability, thereby making welding preheat requirements less critical.

The experimental alloys appear to be comparable to other commercial products for high stress abrasion applications. However, CHT 360 offers better high stress abrasion resistance and is reportedly easy to weld.

DISCUSSION - EFFECT OF MICROSTRUCTURE AND DIRECT QUENCHING ON ABRASION RESISTANCE

The microstructures of the test alloys varied considerably. The Mn/Nb steels and EXP 360-1 consisted of fine grained, acicular ferrite and low temperature decomposition products of austenite, between bands of pro-eutectoid ferrite. The relative amounts of these constituents varied somewhat between alloys.

A representative microstructure is shown in Figure 12. EXP 360-2 (Figure 13), consisted of fine grained ferrite with a visible rolling texture. The large volume of ferrite is probably a result of its very low carbon content. The CHT 100 microstructure (Figure 14) consisted of heavily tempered martensite. CHT 360, 475 and EXP 360-3 had microstructures consisting of tempered martensite, as shown in Figure 15. Microstructures for all alloys have been recorded elsewhere [5].

Although a variation in microstructure between alloys existed, its effect on abrasion resistance was difficult to determine. In low stress abrasion tests, microstructures containing the least amount of ferrite appeared to exhibit the best abrasion resistance. In the high stress tests, the variations in microstructure did not appear to influence abrasion resistance. The effect of direct quenching on abrasion resistance was also difficult to determine. These difficulties originated with the large number of composition, structural and heat treatment variables in the production of the steels. Before the effects of microalloying and direct quenching can be thoroughly evaluated, a systematic approach to the adjustment of these variables is required. Ideally, one of composition, thermo-mechanical treatment or subsequent heat treatment should be varied, while the other two variables are held constant, so that individual effects can be assessed.

CONCLUSIONS

Microalloyed steels produced by direct quenching have similar low stress and high stress abrasion resistance to conventional low alloy steels, with similar hardness levels. Low stress abrasion resistance tended to increase as hardness and carbon content increased, but heat treatment was also important. Little variation in high stress abrasion resistance was obtained over the range of alloys tested. Microalloying would probably be attractive for producing weldable abrasion resistant plate, if hardness levels equivalent to quench and tempered steels can be produced at lower carbon concentrations. This was not achieved with the alloys tested.

RECOMMENDATIONS

1. The abrasion resistance of steels appears to be a complex function of composition, thermo-mechanical treatment, post heat treatment and the microstructure produced by these variables. A systematic study should be undertaken to isolate the effects of each of these variables on abrasion resistance.

2. Pairs of samples with equivalent hardness levels, but produced by microalloying in one case and quench and tempering in the other, should be produced for abrasion testing and comparative weldability tests.

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TABLE I: Chemical Compositions (%)

Element	Mn/Nb Steels				EXP 360 Steels			CHT Steels		
	1	2	3	4	1	2	3	100	360	475
C	0.10	0.16	0.17	0.19	0.15	0.03	0.18	0.13	0.13	0.28
Mn	1.50	1.48	1.34	1.45	1.33	1.36	1.41	1.42	1.42	1.39
Si	0.29	0.24	0.21	0.21	0.26	0.22	0.27	0.29	0.29	0.29
S	0.011	0.015	0.010	0.010	0.035	0.036	0.035	0.014	0.020	0.014
P	0.006	0.010	0.010	0.010	0.009	0.008	0.010	0.007	0.004	0.003
Al	0.08	0.04	0.03	0.03	0.02	0.07	0.04	0.07	0.08	0.07
Mo	0.29	0.24	0.21	0.21	0.23	0.25	0.24	0.21	0.27	0.57
Ni	-	-	-	-	<.01	<.01	<.01	<.01	0.03	0.01
Cr	-	-	-	-	0.05	0.02	0.02	0.02	<.015	0.03
V	-	-	-	-	0.040	0.045	0.040	<.005	<.005	<.005
Ti	-	-	-	-	0.020	0.050	0.055	0.035	0.040	0.035
Nb	0.065	0.060	0.060	0.065	0.055	0.060	-	-	-	-
B	-	-	-	-	0.002	0.0020	0.0019	<.0001	0.0003	0.0002

TABLE II: Rolling Schedules

Operation	Mn/Nb Steels		EXP 360 Steels	
	Temperature (°C)	Mill-gap (mm)	Temperature (°C)	Mill-gap (mm)
Soak	1230	-	1200	-
Pass 1	(1205)	50.8	(1175)	50.0
Pass 2	(to)	44.4	(to)	43.7
Pass 3	(1165)	40.3	(1125)	39.6
Pass 4	900	36.4	900	35.8
Pass 5	875	30.5	880	30.5
Pass 6	850	22.6	860	25.4
Pass 7	825	15.7	840	20.3
Pass 8	800	10.7*	820	15.2
Pass 9	-		800	10.7*

* - 13 mm after spring-back

TABLE III: Identification Numbers and Hardnesses of Test Materials

Alloy	FML Lab. No.	PMRL Heat No.	Hardness	Graph Symbol
Mn/Nb-1	81-826	11892	Rc 32	a
Mn/Nb-2	81-825	11916	Rc 37	b
Mn/Nb-3	81-824	11915	Rc 37	c
Mn/Nb-4	81-827	11918	Rc 44	d
EXP 360-1	81-821	12446	Rc 33	e
EXP 360-2	81-822	12487	Rc 22	f
EXP 360-3	81-823	12486	Rc 39	g

Alloy	FML Lab. No.	CHT Heat No.	Hardness	Graph Symbol
CHT 100	81-613	QT31694	Rc 24	h
CHT 360	81-614	QT32275	Rc 40	i
CHT 475	81-615	QT1287	Rc 50	j

TABLE IV: Ranking of Test Alloys by Low Stress Abrasion Resistance

Alloy	Average Abrasion Factor	95% Confidence Interval	No. of Tests Performed
CHT 475	2.4	2.2 - 2.5	8
Mn/Nb-4	1.73	1.67 - 1.79	8
CHT 360	1.51	1.45 - 1.57	8
EXP 360-3	1.50	1.45 - 1.55	8
Mn/Nb-3	1.31	1.28 - 1.34	8
Mn/Nb-2	1.31	1.25 - 1.37	8
EXP 360-1	1.30	1.24 - 1.36	8
Mn/Nb-1	1.15	1.12 - 1.18	8
CHT 100	1.05	1.00 - 1.10	8
EXP 360-2	1.01	0.99 - 1.03	8

TABLE V: Ranking of Test Alloys by High Stress Abrasion Resistance

Alloy	Average Abrasion Factor	95% Confidence Interval	No. of Tests Performed
CHT 360	1.37	1.33 - 1.41	12
EXP 360-1	1.32	1.25 - 1.39	12
Mn/Nb-2	1.30	1.25 - 1.35	12
EXP 360-3	1.30	1.21 - 1.39	12
Mn/Nb-3	1.29	1.23 - 1.35	11*
Mn/Nb-1	1.28	1.22 - 1.34	12
CHT 475	1.2	1.1 - 1.3	12
Mn/Nb-4	1.2	1.1 - 1.3	12
EXP 360-2	1.14	1.06 - 1.22	12
CHT 100	1.1	1.0 - 1.2	12

* One weight loss discarded because of testing problems.

TABLE VI: Probability That Abrasion Factor Means Are Not Significantly Different

	Mn/Nb-1	Mn/Nb-2	Mn/Nb-3	Mn/Nb-4	EXP 360-1	EXP 360-2	EXP 360-3	CHT 100	CHT 360	CHT 475
Mn/Nb-1	X	55%	70%	30%	35%	< 1%	70%	< 1%	< 1%	15%
Mn/Nb-2	<0.1%	X	75%	25%	60%	<0.1%	100%	< 1%	3%	5%
Mn/Nb-3	<0.1%	100%	X	35%	45%	< 1%	85%	< 1%	3%	10%
Mn/Nb-4	<0.1%	<0.1%	<0.1%	X	20%	50%	25%	30%	5%	100%
EXP 360-1	<0.1%	75%	75%	<0.1%	X	<0.1%	70%	< 1%	20%	3%
EXP 360-2	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	X	< 1%	55%	<0.1%	35%
EXP 360-3	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	X	< 1%	15%	15%
CHT 100	< 1%	<0.1%	<0.1%	<0.1%	<0.1%	10%	<0.1%	X	<0.1%	20%
CHT 360	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	75%	<0.1%	X	< 1%
CHT 475	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	X

Upper triangle compares high stress abrasion factor means, lower triangle compares low stress abrasion factor means.

TABLE VII: Abrasion Factors for Commercial Ferrous Alloys

Alloy	Low Stress Abrasion Factor	High Stress Abrasion Factor	Hardness
Highly Alloyed, White Iron Hardfacing Deposit (5%C, 20%Cr, 9%Mo, 9%Nb)	30 ± 10	3.0 ± 0.3	Rc 68
Tungsten Carbide Hardfacing Deposit (60 wt% WC, Bal. Fe)	17	2.1 ± 0.2	Rc 64
White Iron Hardfacing Deposit (4%C, 25%Cr, 3%Mo)	13 ± 2	2.0 ± 0.2	Rc 60
Heat Treated White Cast Iron (3%C, 16%Cr, 1.5%Ni)	11.6 ± 0.8	1.5 ± 0.1	Rc 65
Cast AISI 8680 - Quenched, Tempered at 205°C	2.7 ± 0.3	1.3 ± 0.1	Rc 60
Cast AISI 4320 - Quenched, Tempered at 205°C	1.9 ± 0.3	1.3 ± 0.1	Rc 41
Mn/Nb-4 Microalloyed, Direct Quenched Steel	1.73± 0.06	1.2 ± 0.1	Rc 44
Cast AISI 8640 - Quenched, Tempered at 540°C	1.58± 0.09	1.4 ± 0.2	Rc 40
Cast AISI 8620 - Quenched, Tempered at 205°C	1.5 ± 0.1	1.2 ± 0.1	Rc 33
Cast Mn Steel - Water Quenched (0.4%C, 13%Mn, 4%Ni)	1.1 ± 0.1	1.1 ± 0.1	Rb 80
1018 Mild Steel - Mill Annealed	1.0	1.0	Rb 93

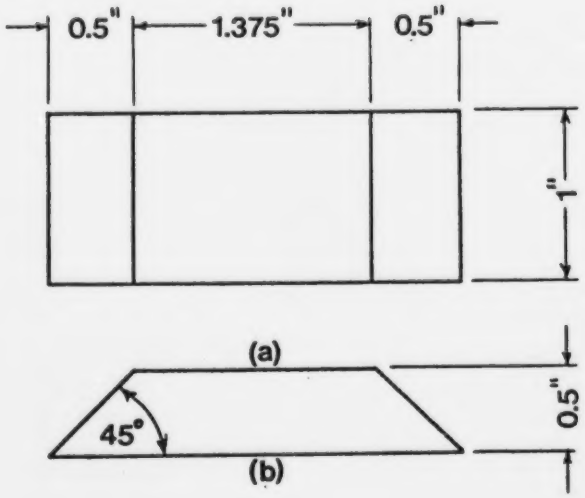

FIGURE 1: Configuration and approximate dimensions of abrasion test samples.

(a) High Stress Abrasion Test Face
(b) Low Stress Abrasion Test Face

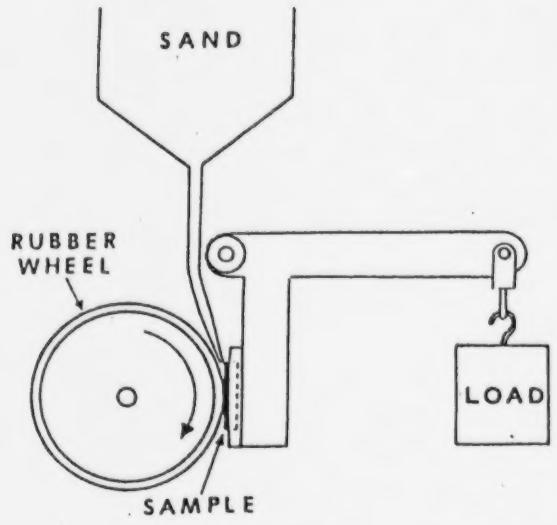

FIGURE 2: Schematic diagram of low stress abrasion test.

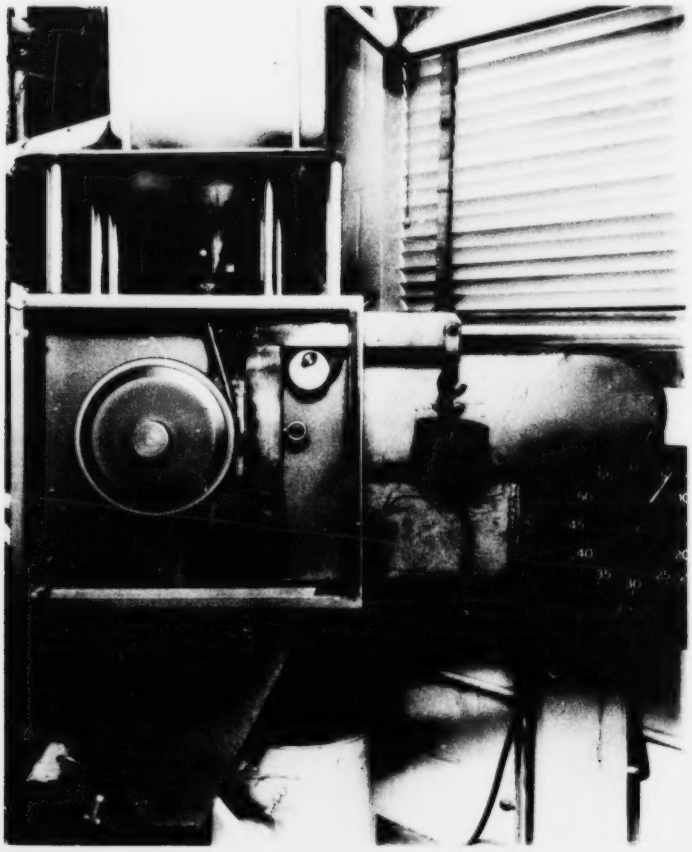

FIGURE 3: Actual low stress abrasion test equipment.

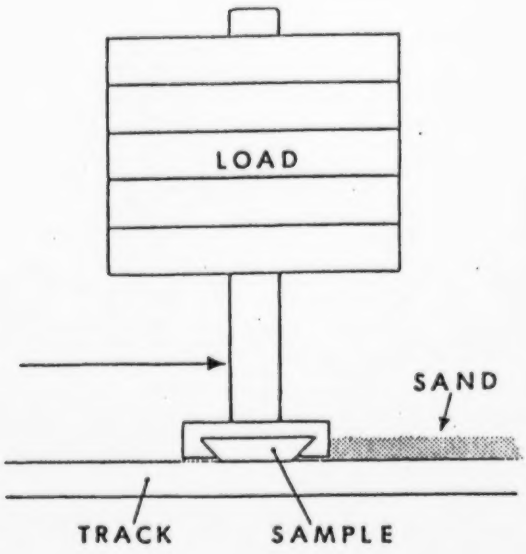

FIGURE 4: Schematic diagram of high stress abrasion test.

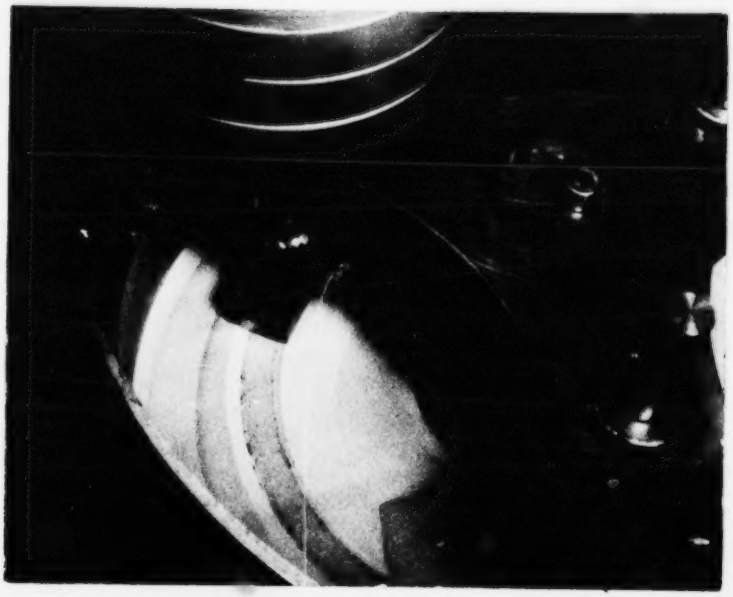

FIGURE 5: Actual high stress abrasion test equipment.

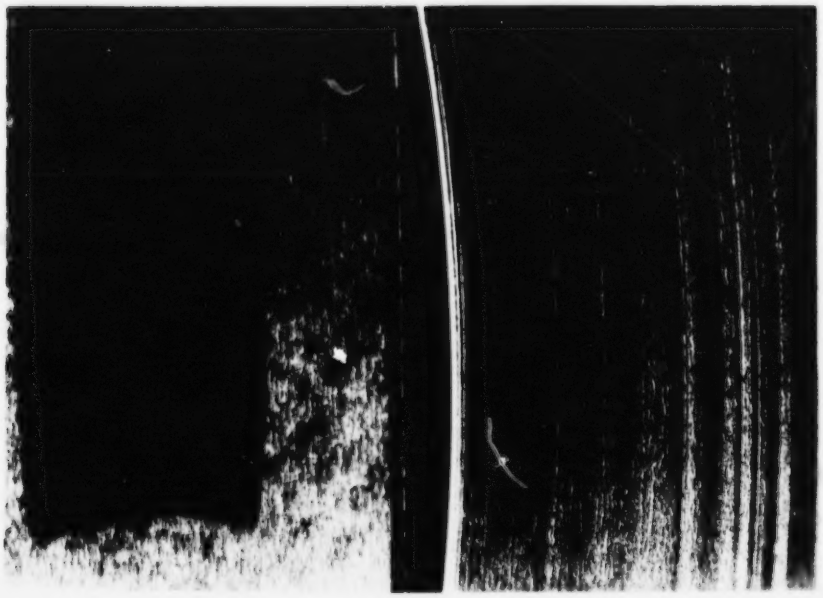

FIGURE 6: Wear scars from low stress abrasion test (left) and high stress abrasion test (right).

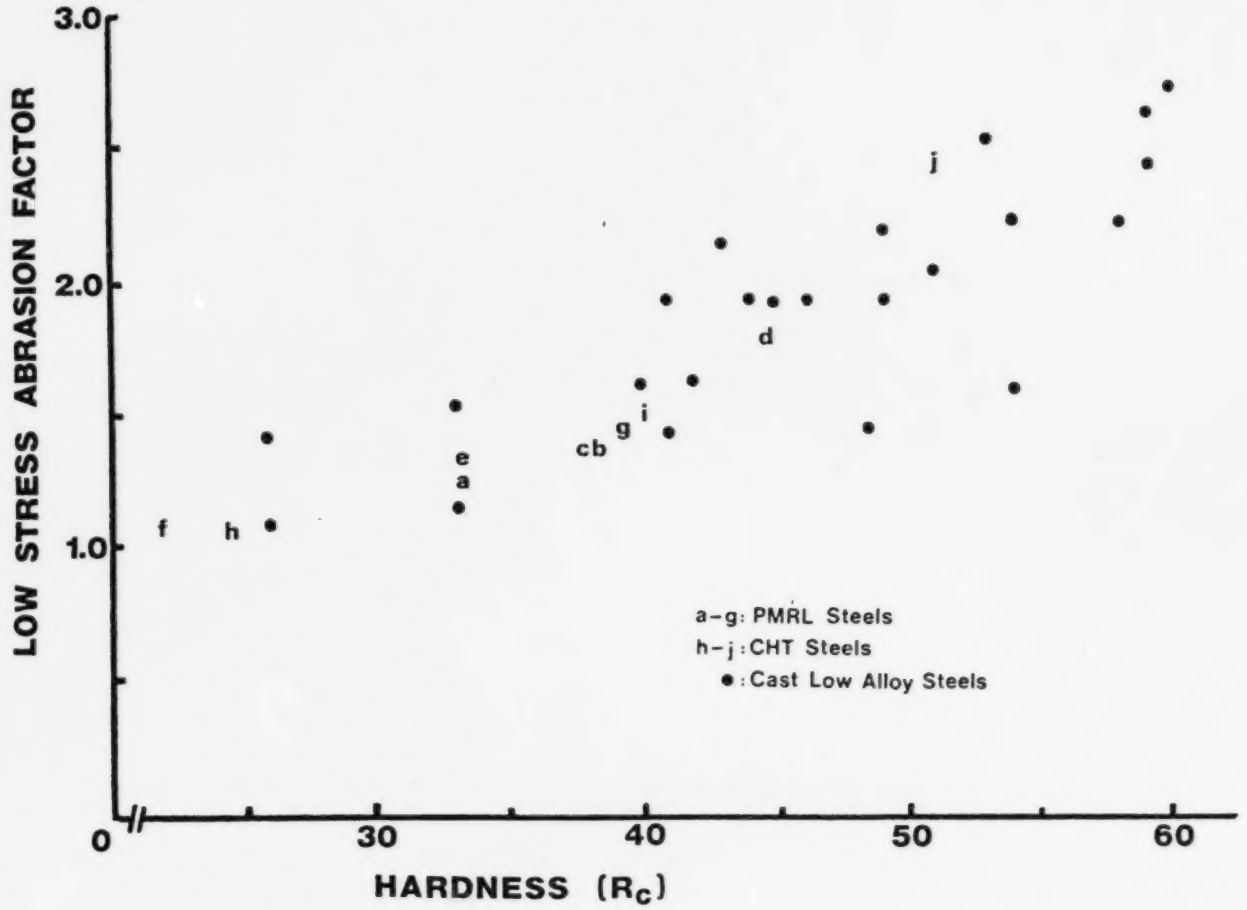

FIGURE 7: Effect of hardness on low stress abrasion resistance.

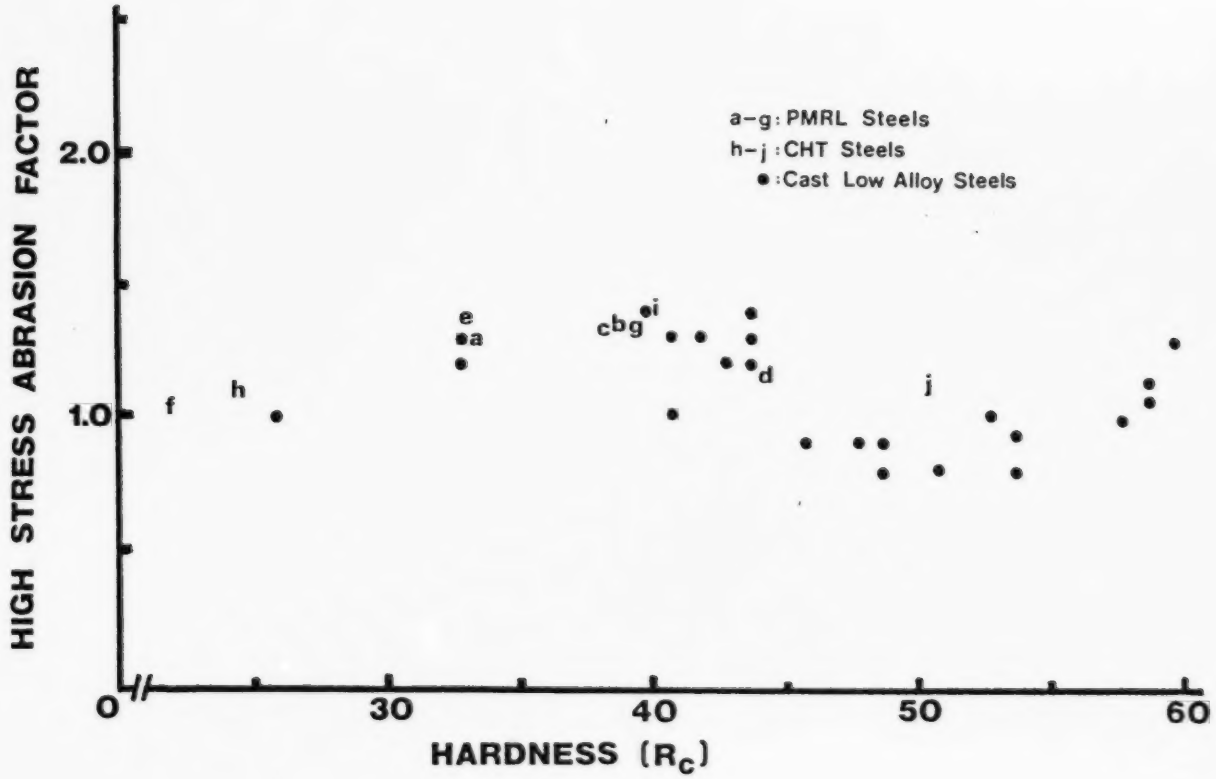

FIGURE 8: Effect of hardness on high stress abrasion resistance.

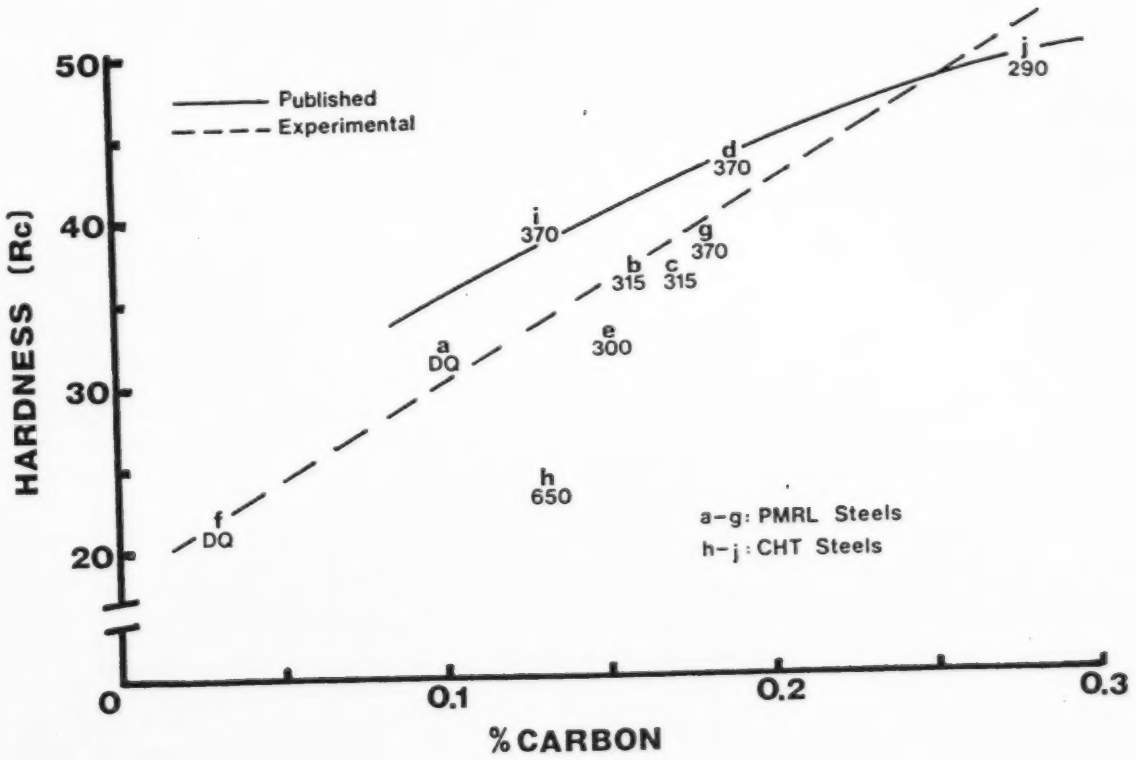

FIGURE 9: Effect of carbon content on hardness of test steels.

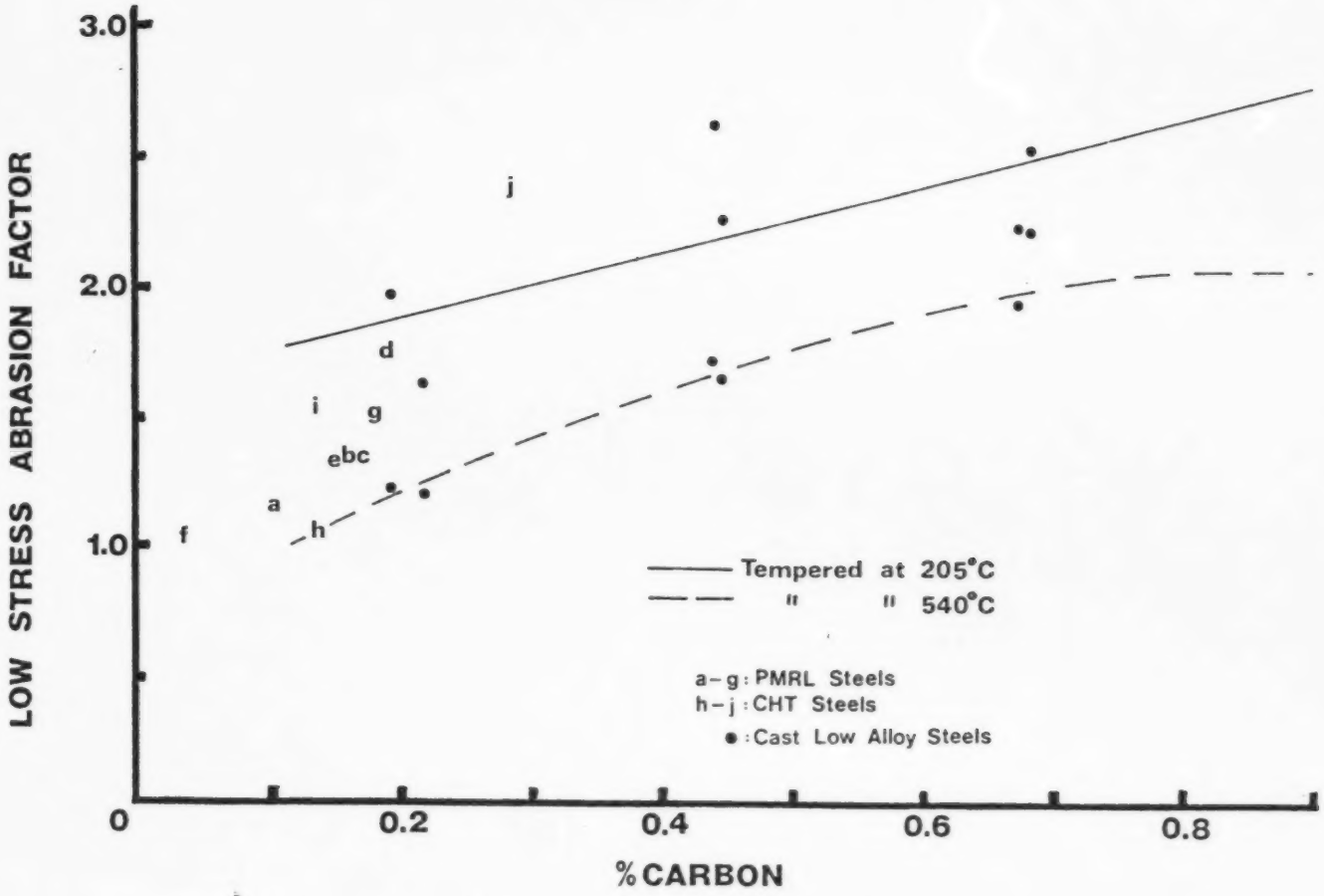

FIGURE 10: Effect of carbon content on low stress abrasion resistance.

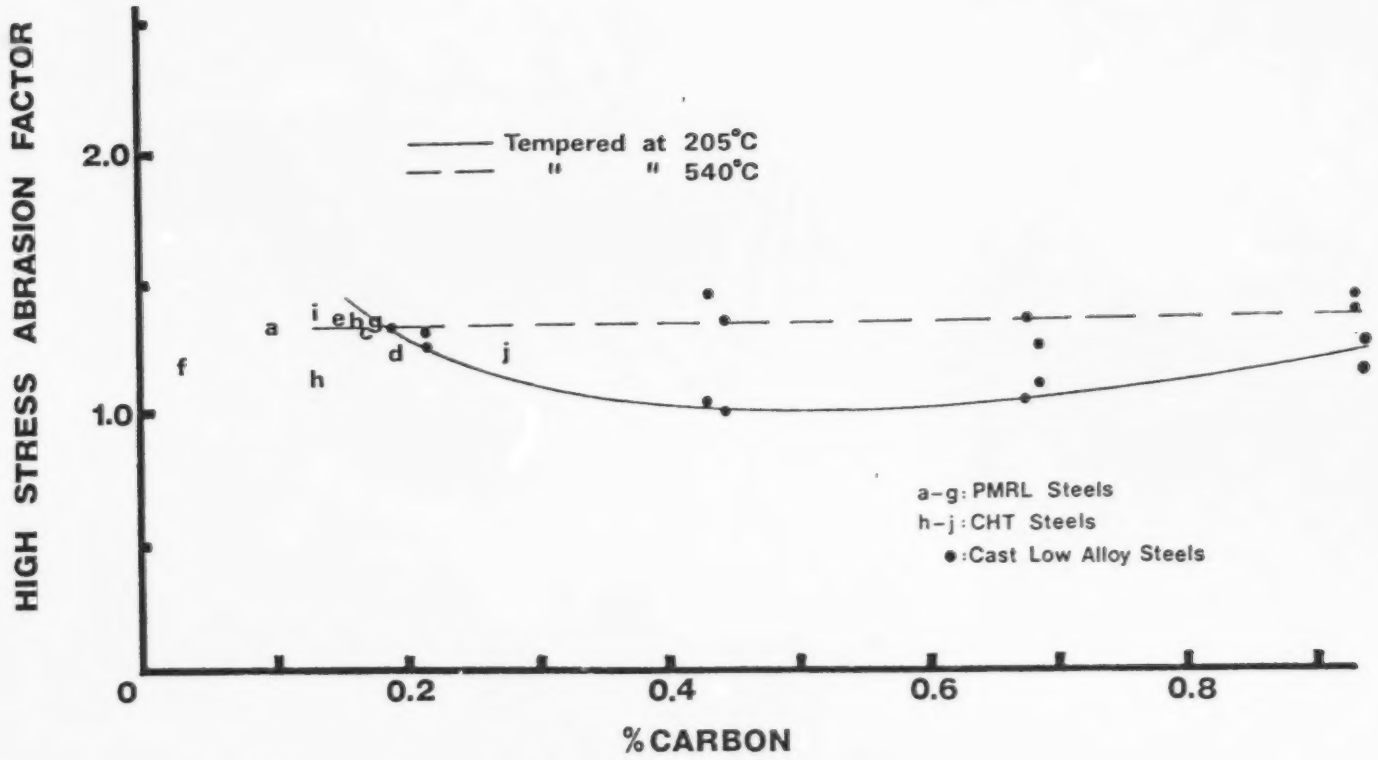

FIGURE 11: Effect of carbon content on high stress abrasion resistance.

FIGURE 12: Microstructure of Mn/Nb-3, consisting of fine grained, acicular ferrite and low temperature decomposition products of austenite, between bands of pro-eutectoid ferrite. All of the Mn/Nb steels and EXP 360-1 consisted of structures of this type. (5% Nital - 500X)

FIGURE 13: Microstructure of EXP 360-2, consisting of fine grained ferrite with a visible rolling texture. (5% Nital - 500X)

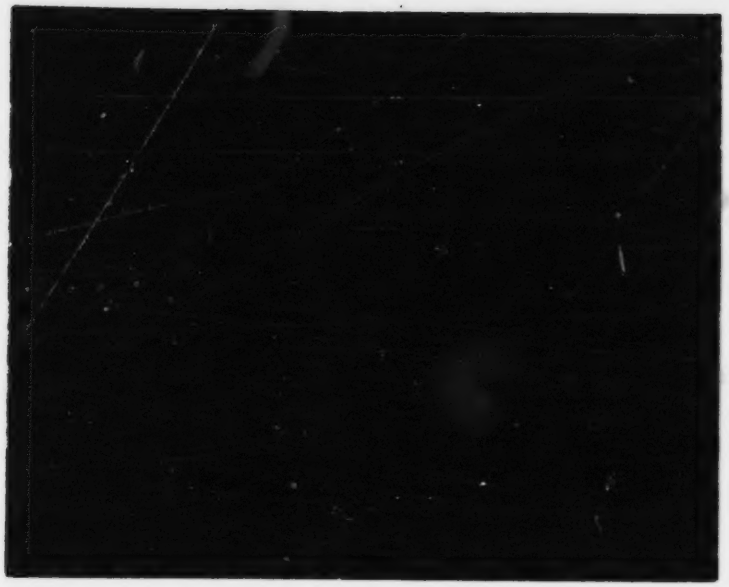

FIGURE 14: Microstructure of CHT 100, consisting of heavily tempered martensite. (5% Nital - 500X)

FIGURE 15: Microstructure of EXP 360-3, consisting of tempered martensite. CHT 360 and 475 also consisted of structures of this type. (5% Nital - 500X)

POOR

QUALITY

ORIGINAL